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TRANSPARENT DISPERSION COMPENSATOR WITH BUILT-IN GAIN EQUALIZER

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Abstract: *In this work we describe a method to obtain a transparent or even an amplifying dispersion compensating module with built-in gain equalization functionality. The principle of operation and experimental results are illustrated.*

Introduction

In high capacity systems both dispersion compensation [1] and dynamic gain equalization [2] is necessary. The latter is for example utilized when the transmitted signal power varies with distance due to a change in the channel count in systems where many channels are dropped or added. Dynamic gain equalization may also be needed in Raman amplified systems where Raman gain is used either to counterbalance the loss of dispersion compensation blocks or in distributed amplifiers. In both the spectral shape of the Raman gain depends on the wavelength(s) of the pump(s) used in the system.

Thus the use of a Raman-pumped dispersion compensating module (DCM) and a dynamic adjustable gain element is easily justified. To obtain a dynamically adjustable gain element one may use multiple pump wavelengths as a pump source for the Raman pumped DCM. By using 3 pumps a gain ripple of 0.3 dB is obtainable at a gain of 8 dB throughout the C-band [3]. Alternatively one may combine the Raman pumped DCM with a dynamic gain equalization (DGE) filter.

Here we describe experimental results on a Raman pumped DCM followed by a DGE. The benefits of this approach compared to the multiple wavelength pumped Raman amplifier include: less sensitivity to the exact wavelength(s) of pump(s), higher spectral resolution, and easy automatic control.

The proposed setup

The proposed module consists of two elements. The first is a Raman pumped DCM. Such a fiber is well suited for Raman amplification since it has high germanium content and a low effective core area. The second element is a DGE, based on waveguide grating routers [4]. The composite noise figure of the proposed module, F, equals:

$$F = F_R + \frac{1-T}{G_R T} \qquad (1)$$

where G_R is the net-gain of the Raman pumped DCM, F_R, the corresponding noise figure, and T the transmission of the DGE. $G_R T$ is the composite gain of the proposed module. The dispersion compensator is transparent when $G_R T$ equals one. In this case the noise figure is between F_R and F_R+1, since the transmission is between 1 (loss less) and 0 (opaque). Thus, the composite noise figure is determined mainly by the Raman pumped DCM.

The noise figure of a Raman pumped DCM can be made small by using a short length of fiber that is highly pumped. The remaining pump power after the short DCM fiber may be re-used either to pump a second piece of dispersion compensating fiber placed after the DGE [5], or as a pump for a distributed Raman amplifier located in front of the proposed module.

Experimental setup

To demonstrate the behavior of the proposed configuration, a model was constructed. In the model, the signal was initially launched into an isolator after which the signal was passed into the DCM. The DCM was counter pumped using a high power pump module emitting light at 1455 nm. Then the signal was launched to the DGE which was remotely controlled using a computer.

The DCM had a dispersion of 330 ps/nm at 1550 nm. The length of the fiber in the DCM was 3.2 km. The loss at the pump wavelength was measured to 0.6 dB/km. The Raman gain coefficient peaked at a value of 2.6 $(\mathrm{Wkm})^{-1}$ for a signal wavelength close to 1555 nm, see Fig. 1.

The peak of the Raman gain coefficient is approximately 4 times that of the peak in a standard dispersion shifted fiber. Using a pump power 330 mW at 1455 nm, a peak on-off Raman gain of 8.7 dB was expected close to 1555 nm, assuming undepleted pump. With a loss of the DCM close to 3 dB at this wavelength, this is approximately the gain required to counterbalance the insertion loss of the DGE. The corresponding noise figure of the Raman pumped DCM is expected to be close to 4 dB.

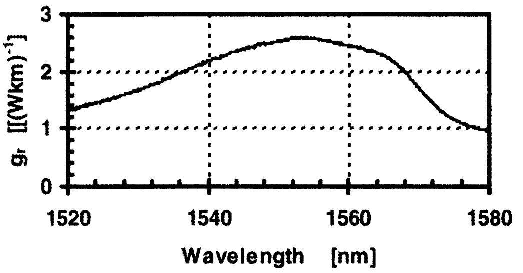

Fig. 1: The measured Raman gain coefficient spectrum for the used DCM module.

The pump module was a high power pump module based on a cascaded Raman resonator [5] emitting light at 1455 nm with maximum output power close to 1 W.

The spectral response of the DGE was adjusted by controlling the attenuation on wavelengths placed on a 100 GHz frequency grid. The DGE was designed for operation in the C-band (1530 nm to 1565 nm).

Results

Figure 2 illustrates the performance of the proposed module. By launching close to 330 mW of pump power to the DCM, the bottom curve, in Fig. 2a was achieved. From this we increased the signal gain, i.e. the ratio of the signal output power to the signal input power, in steps of approximately 2 dB, Fig. 2a. Fig. 2b illustrate the corresponding noise figure

In general, the composite noise figure, fig. 2b, reduces as the composite gain, fig 2a, increases as expected from eqn.(1). The reason for this is that the noise figure of the Raman pumped DCM reduces as the pump power is increased. However, increasing the composite gain from 1 to 3 dB does not lead to a significant reduction in the composite noise figure. This is explained by the insertion loss of the DGE, which in this case was higher around the center-wavelengths, to counter balance the spectral profile of the Raman gain.

The shape of the noise figure curves, fig. 2b, is explained by the applied spectral loss profile. For example in case IV where the Raman gain is significantly higher for the center wavelengths than the wavelengths at the edges of the DGE. In this case, the second contribution, in eqn.(1), to the composite noise figure becomes more significant for the center wavelengths compared to the wavelengths at the edges.

The noise performance in fig. 2b, has to be compared against the performance of a component with similar functionality. As mentioned earlier one alternative is a DCM pumped with multiple pump wavelengths. Such a module may have a noise performance closer to the ideal limit of the proposed setup, i.e. F_R, in eqn. (1), However, it requires the use of multiple pumps and at the expense of an increased gain ripple. Another alternative model consists of an erbium-doped fiber amplifier followed by a unpumped DCM and a DGE. The composite noise figure of such a module will be close to the noise figure of the EDFA, i.e. close to the noise figure of the proposed setup or potentially a dB lower. However, the main drawback of such a module is that its window of operation is limited to the wavelength region of the EDFA.

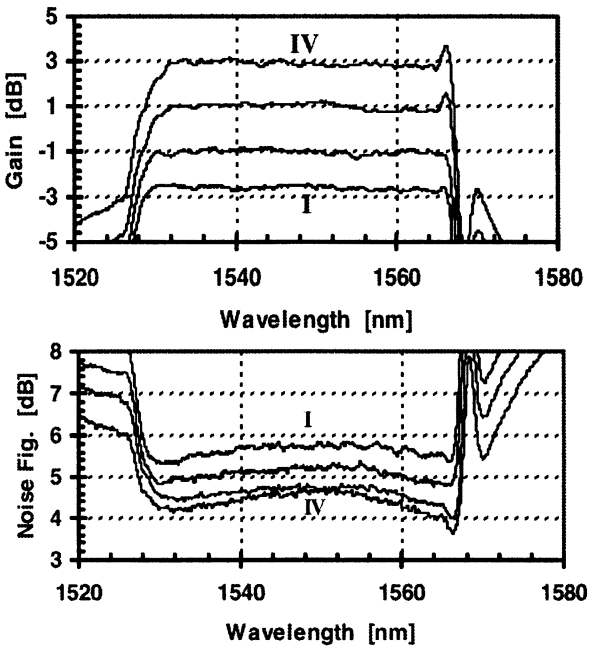

***Fig. 2a (Top)** Measured composite small signal gain versus wavelength for the module and **Fig. 2b (Bottom)** the corresponding noise figure. In both figures, the curves are labeled with increasing pump power.*

Conclusion

A dispersion compensator with built-in dynamic gain equalization is demonstrated. In one example a net-gain of 2.9 dB from 1532 nm to 1564 nm with a gain ripple less than ±0.2 dB, and a noise figure better than 4.5 dB is obtained. In addition, the module is largely tolerant to the wavelength(s) of the pump laser(s), very simple and may be easily redesigned to operate at other wavelengths.

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